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RESEARCH MEMORANDUM

EFFECT OF FUEL ADDITIVES ON CARBON DEPOSITION

IN A J33 SINGLE COMBUSTOR

II - SEVEN COMMERCIAL ORGANO-METALLIC ADDITIVES

By Vincent F. Hlavin and William P. Cook

Lewis Flight Propulsion Laboratory
Cleveland, Ohio

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NATIONAL ADVISORY COMMITTEE
FOR AERONAUTICS

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RESEARCH MEMORANDUM

EFFECT OF FUEL ADDITIVES ON CARBON DEPOSITION IN A J33 SINGLE COMBUSTOR

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SUMMARY

The effectiveness of seven commercial fuel additives in reducing carbon formation in a J33 single combustor was investigated in a No. 2 furnace oil with additional tests being made on two of the additives in a minimum quality MIL-F-5624A, grade JP-4, fuel. These additives were organo-metallic compounds manufactured for a variety of industrial applications. Simulated engine conditions for the tests were zero flight Mach number, 20,000-foot altitude, and 90-percent rated speed for a 4-hour period.

With concentrations of 1/4 to 1 gallon of additive per 1000 gallons of fuel, the weight of carbon deposited in the combustor by the No. 2 furnace oil was reduced more than 60 percent by all but one of the seven additives tested. The largest reduction, 74 percent, was obtained with a 1-gallon-per-1000-gallons concentration of an additive containing principally lead and copper. This same additive in the minimum quality JP-4 fuel gave only a 38-percent reduction in carbon deposition and was not as effective as another additive containing calcium and sodium which reduced carbon 49 percent with that fuel.

The concentration of smoke in the exhaust gases leaving the combustor was not affected by any of the additives tested.

INTRODUCTION

Carbon deposits encountered in current turbojet-engine combustors may affect combustor performance by promoting liner-wall failure, altering air- and fuel-flow patterns, and causing ignition difficulties. Carbon particles also occur in engine exhaust gases as smoke which, while having no measureable detrimental effect on performance, is objectionable from a tactical standpoint. Research on tubular combustors (refs. 1 and 2) shows that carbon deposits and exhaust-gas smoke increase rapidly with increased inlet-air pressure. Thus, with current turbojet-engine

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design trends toward increased engine pressure ratios, methods for effectively reducing carbon and smoke formation are assuming greater importance. Several methods for minimizing carbon formation are (1) combustor redesign, (2) a restriction in the range of fuel properties, or (3) the use of additives in existing jet fuels. Combustor-design changes, experience has shown, frequently require compromises in other engine-performance characteristics, while reductions in the range of fuel properties would limit still further the availability of existing fuel supplies. Therefore, fuel additives are a possible, practical solution for alleviating the carbon problem without altering present standards.

The NACA Lewis laboratory is investigating the use of fuel additives as a means of reducing carbon and smoke formation in turbojet engines. A previous report on this subject (ref. 3) discusses the addition of three organo-metallic compounds and indicates that small concentrations of compounds containing lead and cobalt significantly reduced the carbon deposition of the fuels tested. The results of further research conducted with seven commercial additives are reported herein. These additives are composed of organo-metallic compounds and are manufactured for a variety of industrial carbon-control applications. Fuel-additive concentrations recommended by the manufacturer were followed when specified.

These additives were individually tested with a low-volatility fuel (No. 2 furnace oil) having a high carbon-forming tendency. Additional tests were conducted with two of the more promising additives in a minimum quality JP-4 fuel which produced about the same weight of carbon as did the low-volatility fuel. The deposition data were obtained along with measurements of exhaust-gas smoke concentration in a J33 single combustor operating at simulated engine conditions of 90-percent rated speed at zero flight Mach number and 20,000-foot altitude for a 4-hour period.

FUELS AND ADDITIVES

A No. 2 furnace oil (NACA fuel 53-193) producing a relatively high average carbon-deposit weight of 20.5 grams per 4-hour test was used as the base fuel for the additives tested. In addition, two of these additives were tested in a minimum quality MIL-F-5624A, grade JP-4, fuel (NACA fuel 54-41) having a comparable carbon-deposit weight of 22.9 grams per test run. The chemical and physical properties of both these fuels are presented in table I.

The seven additives investigated varied somewhat in their commercial applications. They included Diesel fuel additives, gasoline additives, and a furnace cleaner. None were developed specifically for turbojet

application, but all were intended to remove or retard carbon and soot formation resulting from the combustion of low-grade fuels. A list of the additives investigated, their principal constituents, and the concentrations used are presented in the following table:

Additive	Principal constituents	Concentrations tested	
		Volume, gal of additive/ 1000 gal of fuel	Weight, percent by weight of blend
A ^a	Lead, copper	1 .50	0.1062 .0532
B	Copper, calcium	1	.0982
C	Chromium	.91	.1000
D ^a	Calcium, sodium	.25	.0299
E	Cobalt	1.06	.1096
F	Lead, cobalt	1	.0970
G	Calcium	1 .50	.0975 .0488

^aAdditives investigated in both base fuels.

Determinations of the principal constituents contained in the additives were made spectroscopically. In most cases the concentrations employed were those specified by the manufacturer.

APPARATUS AND PROCEDURE

Equipment installation. - A J33 single tubular combustor, shown in figure 1, was used for this investigation. The combustor and auxiliary equipment is shown schematically in figure 2, and this equipment, together with the necessary instrumentation, is described in detail in reference 4. Combustion-air flow was measured by a square-edged orifice plate installed according to A.S.M.E. specifications; inlet-air temperatures were automatically maintained by an electric heater. Fuel-flow rates were measured by a calibrated rotameter. Thermocouple temperature measurements were indicated on automatic-balancing potentiometers, and pressures were measured by absolute manometers.

Smoke samples were obtained by means of a probe centrally located in the exhaust duct of the combustor housing, 50-inches downstream from the fuel nozzle. The probe consisted of 1/4-inch Inconel tubing curved upstream to allow parallel entrance of the gases. Exhaust gases were drawn through the probe to a filter-type smoke meter. Details of this meter are described in reference 2.

Test procedure. - Carbon-deposition and smoke-density measurements were obtained for each of the fuel-additive blends at combustor conditions simulating 90-percent rated engine speed, 20,000-foot altitude, and zero flight Mach number for the J33 turbojet engine. The test conditions were as follows:

Inlet-air pressure, in. Hg abs	53.9
Inlet-air temperature, °F	271
Exhaust-gas temperature (approx.), °F	1100
Air flow, lb/sec	2.87
Fuel flow, lb/hr	127.3
Fuel-air ratio, lb fuel/lb dry air	0.0123
Run time, hr	4

Preceding operation of the test facilities, the combustor liner and dome assembly, the ignition plug, and the fuel-nozzle tip were thoroughly cleaned with the aid of mechanically rotated wire brushes. The clean combustor and ignition plug were then weighed on a torsion balance and installed in the housing. At regular intervals during the test, exhaust-smoke density samples were obtained from the smoke meter on grade No. 4 filter paper. Relative smoke density was then determined by a visual comparison between the filtered deposit and a graded Bacharach Oil Burner Smoke Scale, No. R685. Upon completion of the run, the assembly was reweighed together with that carbon which had formed on the nozzle tip; the difference in the weight of the assembly before and after the test run represents the amount of carbon deposited. In addition to these measurements, sufficient data were obtained to calculate the values of combustion efficiency (the ratio of the actual to the ideal enthalpy rise across the combustor).

Additives were calculated on a weight-concentration basis, and then blended with the base fuel by mechanical mixing. Upon completion of each additive test series, the fuel system was drained and purged to remove any residual additive. Check runs were then made with the base fuel to determine both the effectiveness of the purge and the continued uniformity of carbon deposition of the base-fuel stock.

RESULTS AND DISCUSSION

A summary of the carbon-deposition data obtained with two fuels and seven commercial additives in a J33 single combustor is presented in table II. For most of the determinations, two to three tests were made to insure representative average results. Deviations in the weight of carbon deposited in these check runs averaged less than 11 percent in all cases and compared favorably with the reproducibility obtained in previous investigations (such as, ref. 5).

Figure 3(a) compares the amount of carbon deposit by the No. 2 furnace oil (fuel 53-193) with those amounts deposited by the fuel-additive blends. All the additives tested, with the exception of additive G, reduced the weight of carbon deposited by the base fuel more than 60 percent. As shown on the graph the largest reduction, about 74 percent, resulted from the addition of a 1-gallon-per-1000-gallons concentration of additive A (a furnace soot remover containing lead and copper). The 1/2-gallon-per-1000-gallons concentration of this additive was only slightly less effective, reducing carbon deposition of the base fuel about 70 percent.

Two of the additives which were highly effective in the furnace oil, additive D and the high concentration of additive A, were also tested in a minimum quality JP-4 fuel (fuel 54-41) having an average carbon-deposition weight slightly higher than that of the furnace oil. Results of these tests are shown in table II and figure 3(b). The resulting carbon weight reductions of 49 percent for additive D and 38 percent for additive A indicate that neither was as effective with the JP-4 fuel as with the furnace oil; the relative effectiveness was also reversed in this instance, with additive D giving a greater percentage reduction than additive A.

These carbon-deposition studies indicate that substantial reductions in deposits can be obtained through the use of any one of several commercial additives. It was observed, however, that the relative effectiveness of at least two of the additives was a function of the base fuel used. This indicates that the choice of the best additive for use in jet fuels must result from tests with as many widely different fuels as are obtainable under existing fuel procurement specifications. The results also substantiate, qualitatively, the effectiveness of organo-metallic compounds in reducing carbon deposition. Limited field experience has indicated marked corrosion difficulties in the exhaust section of turbojet engines operating with fuels containing tetraethyl lead, such as high-octane aviation gasoline and "jet mix" (a mixture of high-flash kerosene and aviation gasoline). Reference 3 shows that effective reductions in carbon deposition can be obtained with as little as 0.002 weight percent of lead, which is about 1/80 of the maximum quantity used in aviation gasoline and about 1/20 of that present in current "jet mix". The possible corrosion of turbine blades, however, should be investigated with all prospective fuel additives before recommending them for turbojet application.

Smoke density of the combustor exhaust gas was unchanged by the addition of additives. The highest smoke densities were encountered at the start of each test run and gradually decreased in value as equilibrium temperature conditions were established. Measured combustion efficiencies ranged between 94 and 97 percent for both fuels, and were also unaffected by the presence of additives in the fuel.

SUMMARY OF RESULTS

The following results were obtained from an investigation of the effect of seven commercial fuel additives on the carbon-forming characteristics of two fuels in a J33 single combustor:

1. Six of the seven additives tested decreased carbon deposition of a furnace-oil base fuel at least 60 percent; the largest reduction, 74 percent, was obtained with a 1-gallon-per-1000-gallons concentration of an additive containing principally lead and copper.

2. Two of the more promising additives gave a smaller reduction in carbon deposition when each blend was used with a minimum quality JP-4 fuel; the largest reduction, 49 percent, was obtained with a 1/4-gallon-per-1000-gallons concentration of an additive containing principally calcium and sodium compounds.

3. Exhaust-gas smoke densities were unaffected by the presence of additives in either the furnace oil or the JP-4 fuel.

Lewis Flight Propulsion Laboratory
National Advisory Committee for Aeronautics
Cleveland, Ohio, August 27, 1954

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5. Jonash, Edmund R., Wear, Jerrold D., and Cook, William P.: Carbon-Deposition Characteristics of MIL-F-5624A Fuels Containing High-Boiling Aromatic Hydrocarbons. NACA RM E52G11, 1952.
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TABLE I. - PHYSICAL PROPERTIES OF BASE FUELS

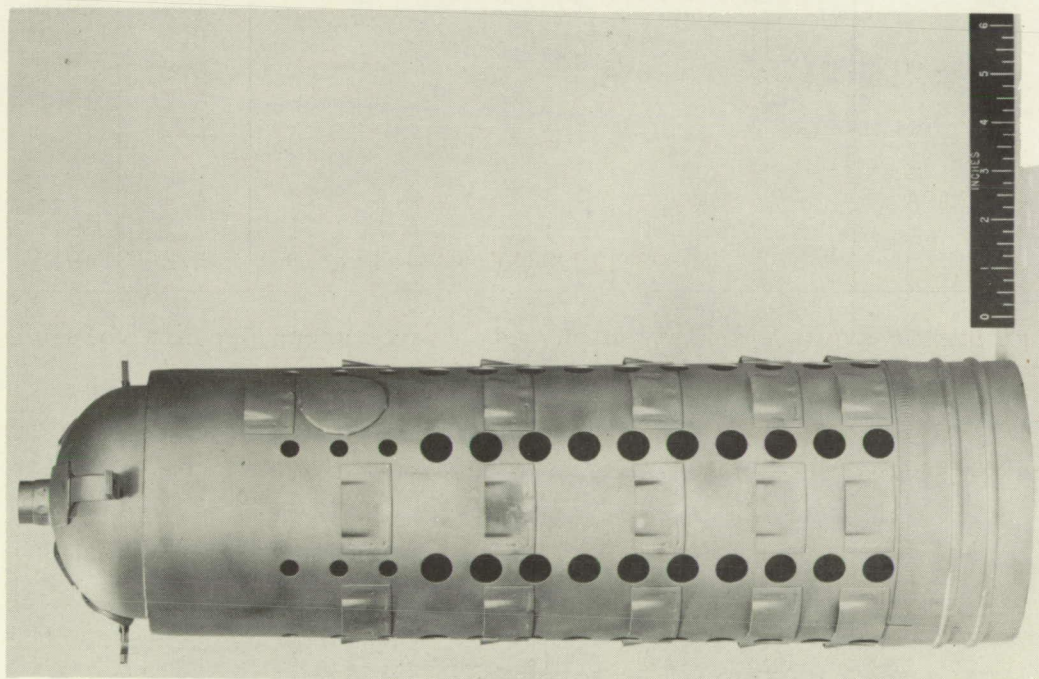
	NACA fuel	
	53-193 (No. 2 furnace oil)	54-41 (JP-4)
A.S.T.M. distillation D86-46, °F		
Initial boiling point	374	146
Percent evaporated		
5	422	198
10	434	235
20	462	278
30	484	312
40	504	339
50	520	359
60	534	393
70	548	434
80	564	477
90	591	521
Final boiling point, °F	627	572
Residue, percent	1.5	1.2
Loss, percent	0	0.8
Freezing point, °F	-13	< -76
Accelerated gum, mg/100 ml	48	75
Air-jet residue, mg/100 ml	7	27
Aromatics, percent by volume		
A.S.T.M. D-875-46T	25.2	26.5
Silica gel	31.5	31.0
Specific gravity, 60°/60° F	0.861	0.825
Bromine number	7.8	7.0
Reid vapor pressure, lb/sq in.	0	2.3
Hydrogen-carbon ratio	0.145	0.159
Net heat of combustion, Btu/lb	18,400	18,300
NACA K factor ^a	423	326

^aRef. 6.

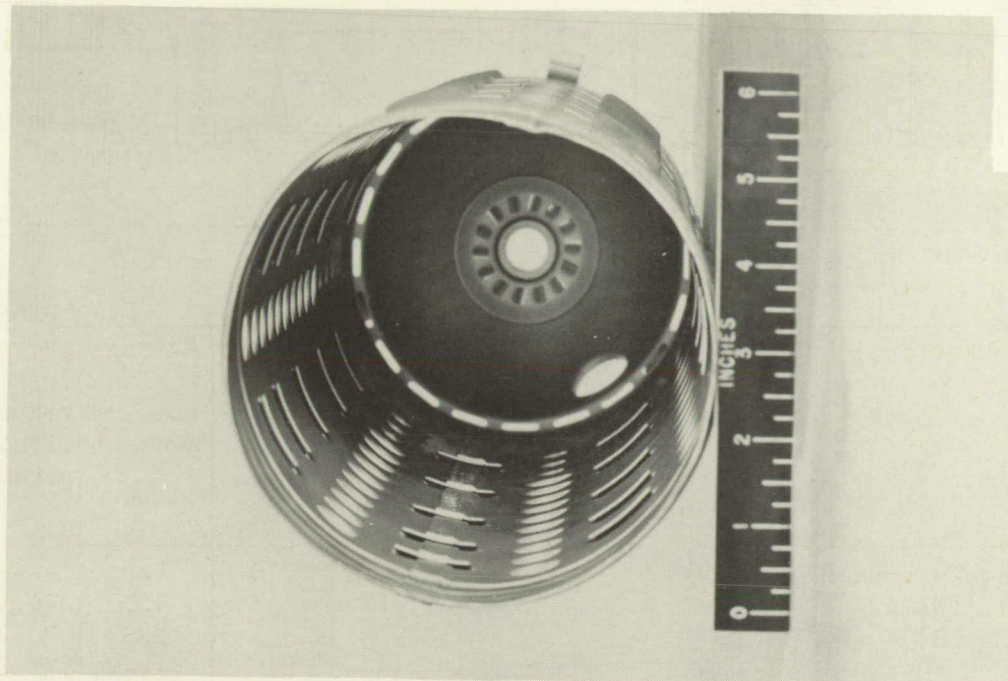
TABLE II. - CARBON-DEPOSITION DATA

Base fuel	Additive	Additive concentration, percent by weight	Carbon deposition, g			Average carbon deposition, g	Average variation, ^a percent	Average carbon reduction, percent
			1	2	3			
No. 2 furnace oil (NACA 53-193)	-	-----	20.7	20.6	20.1	20.5	1.1	----
	A	0.1062	4.9	5.6	----	5.3	6.6	74.1
	A	.0531	5.9	6.2	----	6.1	1.6	70.2
	B	.0982	5.8	----	----	5.8	----	71.7
	C	.1000	6.5	5.9	----	6.2	4.8	69.7
	D	.0299	6.5	6.3	----	6.4	1.6	68.8
	E	.1096	7.3	6.5	----	6.9	5.8	66.4
	F	.0970	8.2	6.5	----	7.4	10.8	63.9
	G	.0975	15.6	18.0	19.8	17.8	8.2	13.2
	G	.0488	16.6	----	----	16.6	----	19.0
JP-4 (NACA 54-41)	-	-----	21.4	23.3	24.0	22.9	4.4	----
	A	0.1062	13.1	15.1	----	14.1	7.1	38.4
	D	.0299	12.2	11.0	----	11.6	5.2	49.3

^aArithmetic average variation of individual carbon deposit values from arithmetic average deposit value.



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Figure 1. - Inner liner and dome of J33 single combustors.

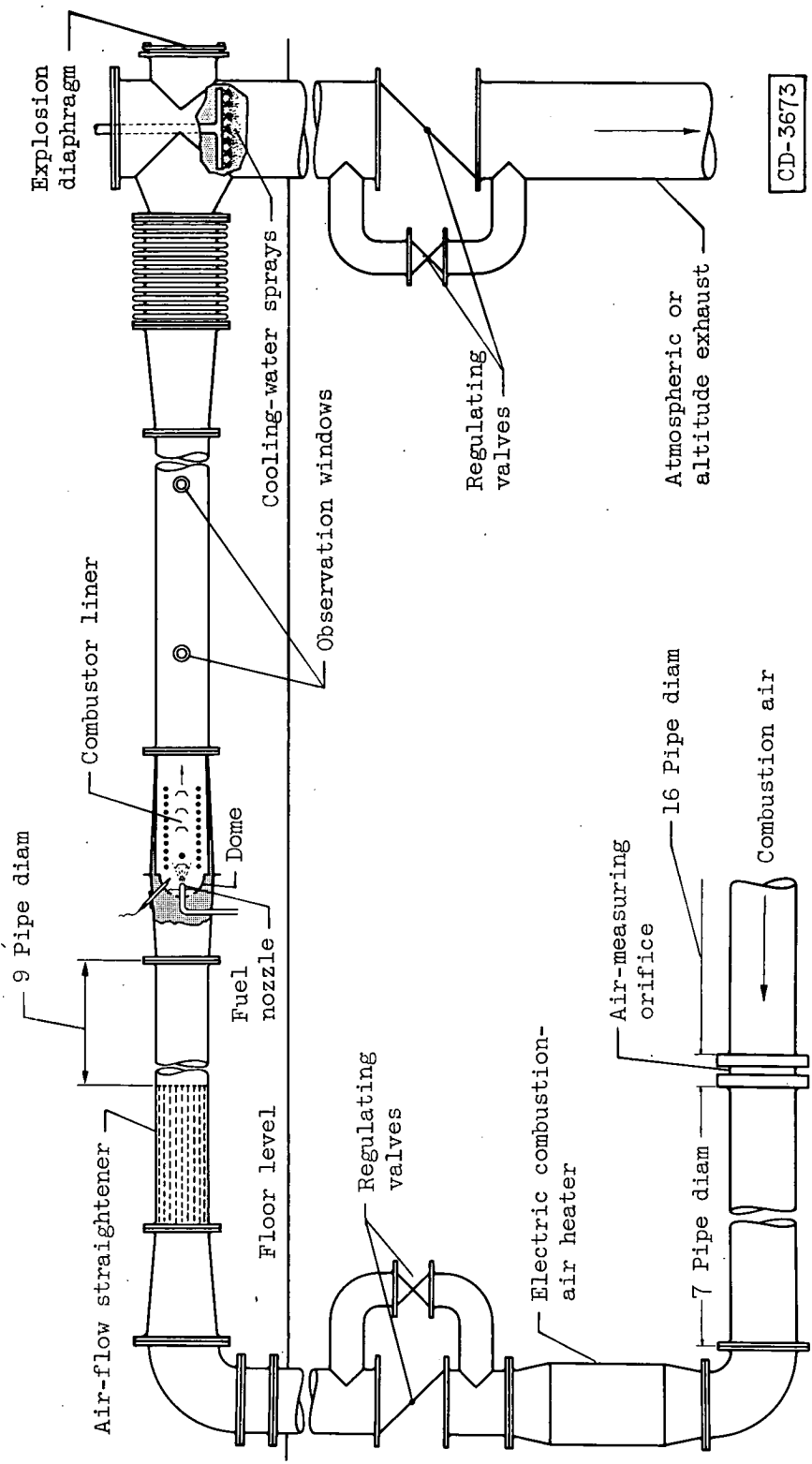
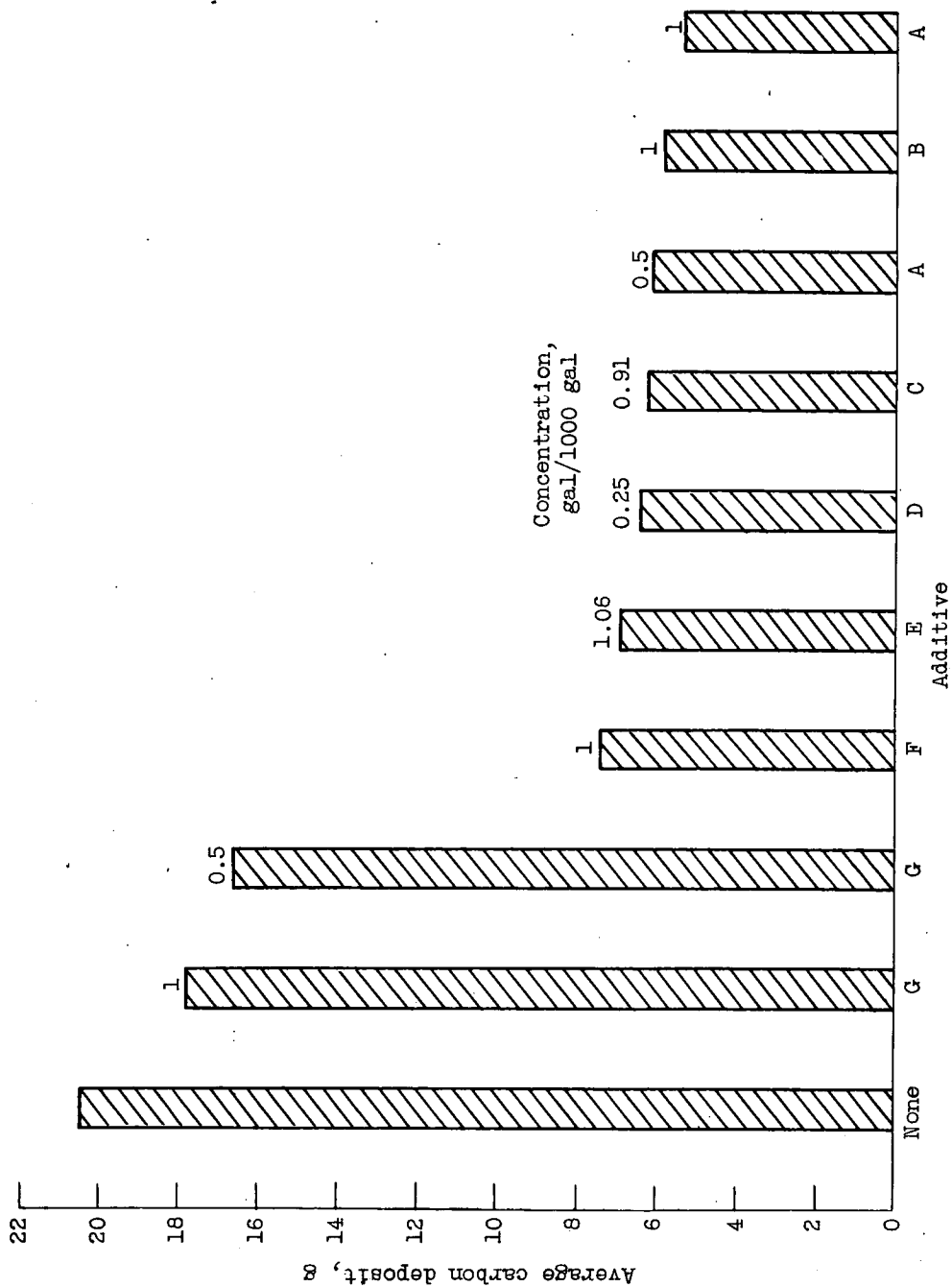
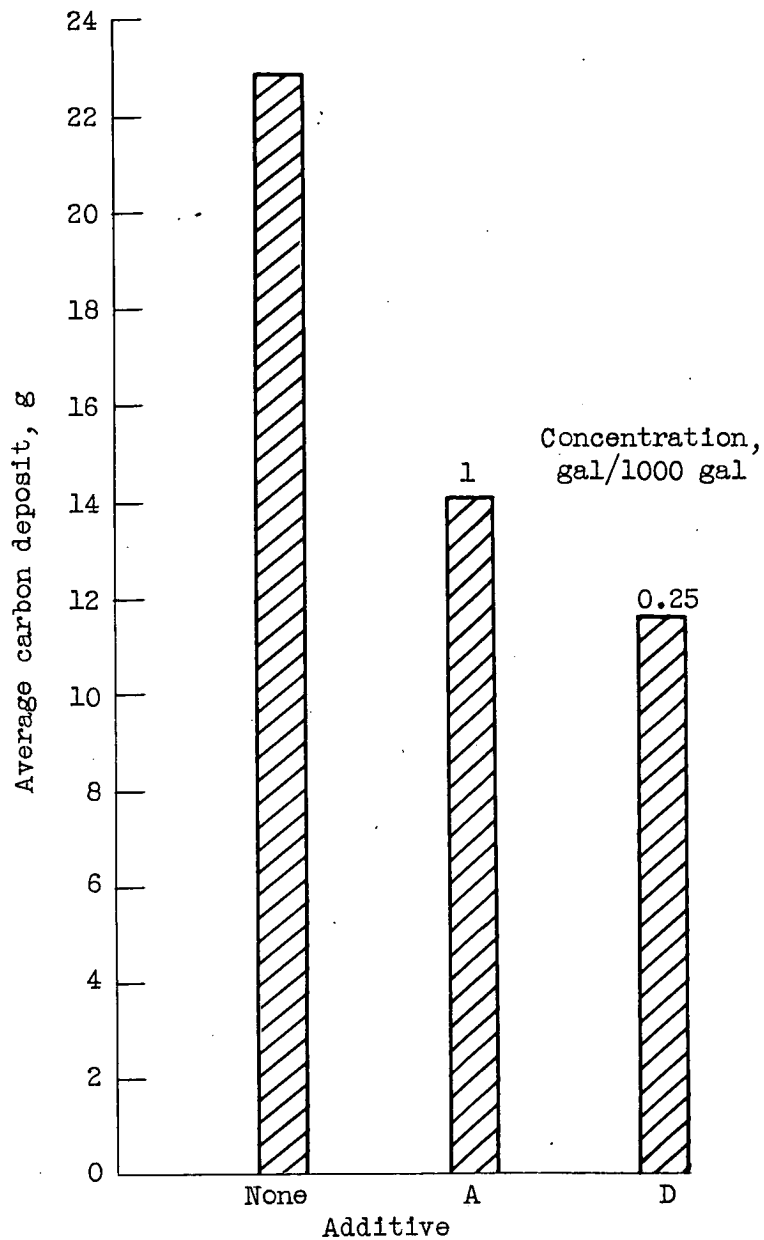


Figure 2. - Single-combustor installation and auxiliary equipment.



(a) No. 2 furnace oil (NACA 53-193).

Figure 3. - Effect of additives on carbon deposition obtained with two base fuels in a single tubular turbojet combustor.



(b) Minimum quality JP-4 fuel (NACA 54-41).

Figure 3. - Concluded. Effect of additives on carbon deposition obtained with two base fuels in a single tubular turbojet combustor.

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